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COASTAL EROSION IN RELATION TO SEA LEVEL CHANGES, SUBSIDENCE AND RIVER DISCHARGE, NILE DELTA COAST

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ABSTRACT

The Nile Delta coast has been dynamically unstable for centuries. Before 1900, its delta front was prograding seaward but after it began to retreat. Examination of the 1988 shoreline survey in relation to the 1909 shows that the total loss of land was 14.7 km² for Rosetta, 0.44 km² for Burullus and 21.0 km² for Damietta. The maximum rate of erosion was found to be 58 m/year at west of Rosetta.

Sea level gauges were installed for records along the coast. The tides are semi-diurnal in nature with two high and two low water levels in a tidal day. A considerable difference was found between water levels of summer and winter seasons. The swell action at Burullus during summer seasons and the effect of winter waves at Rosetta may cause the increasing of sea level and hence coastal erosion. Many evidences indicate that subsidence is partly responsible for erosion.

A significant difference occurred in the Nile load prior and after 1900. The Nile flood levels became lower and the annual sediment load decreased. Furthermore, the closure of the Aswan High Dam in 1964 has reduced the flow and sediment load of the River Nile to insignificant quantities.

Sea level rise and/or subsidence possibly coupled with reduction of the sediment load of the River Nile became paramount importance in recent coastal erosion along the Nile Delta coast.

INTRODUCTION

The coastline of the Nile Delta is a part of the low sandy shore bordering the southeastern part of the Mediterranean sea. The total length of the Nile Delta coastline is about 260 km from Alexandria to Port Said *(Fig. 1)*. Coastal dunes with elevations up to 30 m act as barriers against the action of the sea waves along the eastern part of the Burullus coast. The hydrodynamic factors affecting the coast are the waves, currents and winds. The predominant direction of the waves is NNW with an average height of 80 cm. The eastward littoral current predominates with an average velocity of 36 cm/sec. The prevailing wind comes from the WNW, NW, W and N. The majority of the daily readings range between 9—23 knots/hour. The average tidal changes along the delta coast are small and not exceeding 26 cm.

The stability of coastline depends upon the balance between the quantity of sediment supplied to the coast and that carried away. Formerly, because of the large amounts of sediments brought to the coast by the Nile, depositional forces prevailed near the main discharge points of Rosetta and Damietta. Erosional processes are confined to the coast since 1909 and accelerated after the construction of the Aswan High Dam in 1964 due to reduced Nile sediment inputs.

An increasing body of evidences (HICKS, 1978; HICKS *et al.*, 1983; HULL and TITUS, 1986) suggests that in the coming 100 years a global warming due to the

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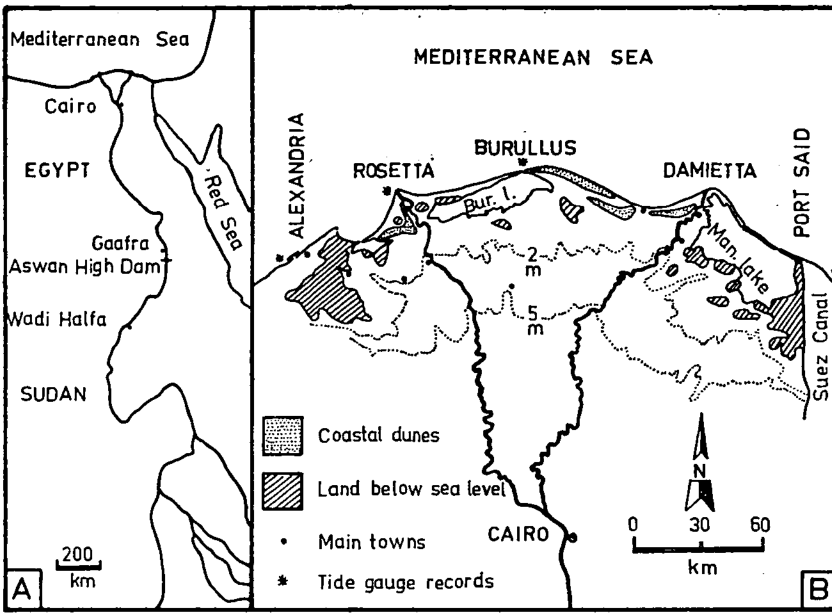

Fig. 1. Location map for the River Nile (A) and the Nile Delta coast (B)

greenhouse effect will lead to a rise in sea level from 0.5 m to 3.5 m. The sea level rise in future coupled with a possible increase in storm surges would cause severe erosion, flooding of reclaimed lands, salt water intrusion and public health risks as well as direct damage to ports, towns and roads of the Nile Delta coast. Over 20% of the coastal land in the Nile Delta could be flooded with a 2 m rise in sea level.

The present study on the Nile Delta coast aims to investigate the the recent coastal erosion in relation to sea level changes, subsidence and reduction of the River Nile inputs. The impacts of future sea level rise in aquifers and estuaries of the northern coast are also discussed.

RATE OF COASTAL EROSION ON HEADLANDS

Erosion of the Nile Delta beaches has been observed long before the construction of the Aswan High Dam. Severe coastal erosion is predominating on the Rosetta, Burullus and Damietta headlands. Many summer houses located on the beach have been destroyed by the sea advance. A cut of about 1 m high in the beach sediments characterizes the eroded area. Coastal dunes are severely eroded due to the attack of waves.

The changes in coastal areas and length were investigated for Rosetta, Burullus and Damietta headlands from the beginning of erosion in 1909 to 1988 *(Fig. 2)*. The total area of erosion in square meters for the three headlands is calculated by comparing the shoreline of 1909 with that of 1988 (Table 1). The loss of coastal lands was about 14.7×10^6 m^2 for Rosetta, 0.44×10^6 m^2 for Burullus and 21.0×10^6 m^2 for Damietta. On each headland, it is observed that the eastern part is eroded faster than the western one. The slow erosion at Burullus may be related to its extension

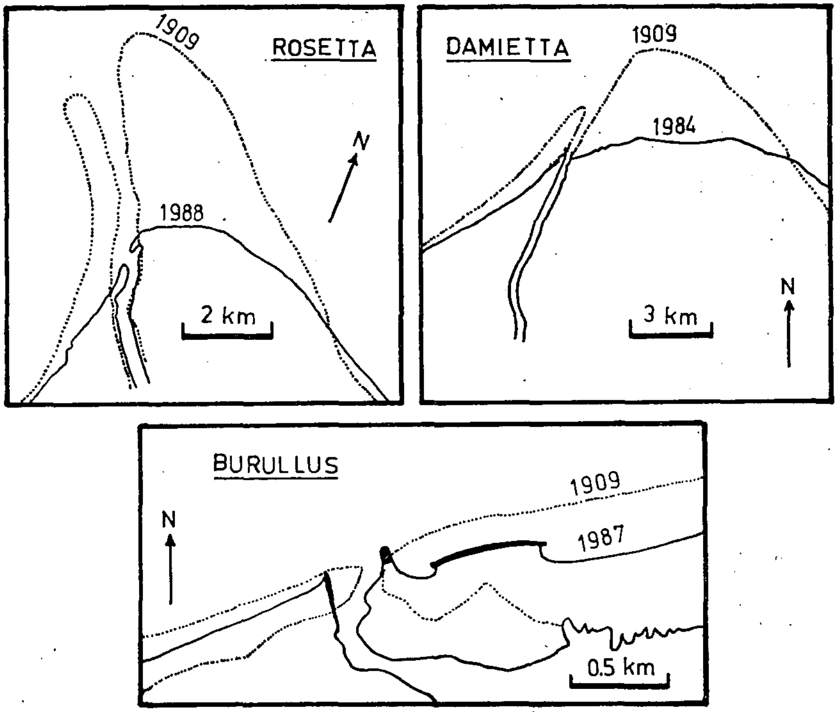

Fig. 2. Shoreline changes at Rosetta, Burullus and Damietta headlands during 1909—1988

and less curved shape than on the other headlands. The rate of erosion was calculated to be 184.000 m²/yr for Rosetta, 5.500 m²/yr for Burullus and 263-000 m²/yr for Damietta. The decrease in maximum length from the extremity of the point during the period 1909—1988 was found to be 4.6 km for Rosetta, 0.3 km for Burullus and 3.3 km for Damietta. The fastest rate of shoreline receding was observed at Rosetta (58 m/yr) if it is compared to 41 m/yr for Damietta and 3.8 m/yr for Burullus.

TABLE 1

Changes in areas and length of Rosetta, Burullus and Damietta, headlands during 1909—1988

Stretch	Eroded area ($\times 10^6$ m²)	Erosion rate (m²/yr)	Decrease in max length (m)	Dc. rate in length (m/yr)
West Rosetta	3.50	44,000	4.600	58.0
East Rosetta	11.20	140,000	4.250	53.0
West Burullus	0.09	1,100	100	1.3
East Burullus	0.35	4,400	300	3.8
West Damietta	4.20	53,000	1.900	24.0
East Damietta	16.80	210,000	3.300	41.0

Sea level change is essential in delineating the position of shoreline. Automatic water level gauges were installed for records along the Nile Delta coast in different times an at different areas. Continuous reading of the water level was made 24 hours a day. In order to define the sea level change, the following levels and their variability were determined: (1) The mean water level (MWL). (2) The mean high water level (MHWL). (3) The highest high water level (HHWL). (4) The mean low water level (MLWL). (5) The lowest low water level (LLWL).

Sea level records were available at Alexandria for the period 1985—1986, at Rosetta for the period 1982—1983 and at Burullus for the period 1984—1985 *(Figs. 3, 4* and *5)*. The sea level characteristics are referred to the Survey Department Zero Level in Egypt. Harmonic analysis of the water level records along the Nile Delta coast indicated that the tides are semi-diurnal in nature with two high and two low water levels in a tidal day with comparatively little diurnal inequality.

At Alexandria and Burullus, a considerable difference was found between water levels of summer and winter seasons *(Figs. 3* and *5)*. It is indicated that the summer

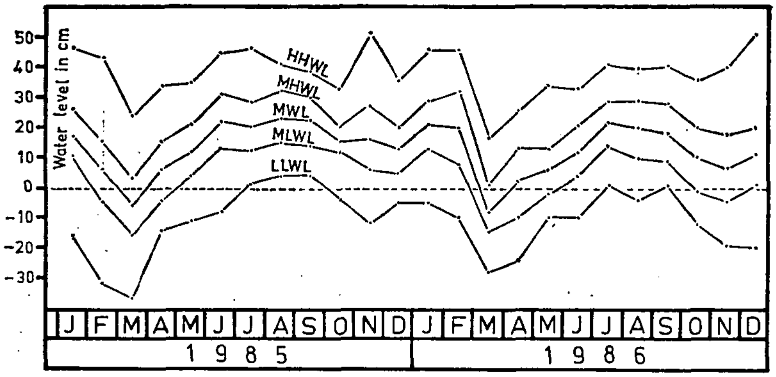

Fig. 3. Sea level changes at Alexandria, 1985—1986

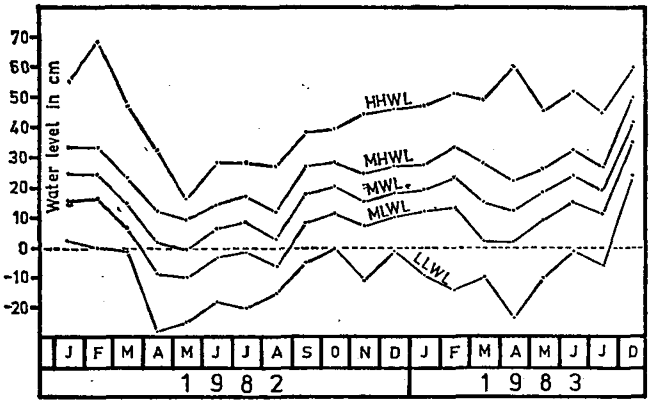

Fig. 4. Sea level changes at Rosetta, 1982—1983

seasons have higher water levels than that in winter ones. The swell action (MANOHAR, 1976) during summer months of June, July, August and September may cause the increasing of the water levels considerably during those months. These high water levels during summer seasons may explain the severe erosion of the beach and coastal dunes at Burullus.

On the other hand, water levels of summer and winter seasons at Rosetta show contrast situation *(Fig. 4)*. Water levels become high in winter and low in summer. Consequently severe coastal erosoion at Rosetta headland may be related to the effect of the winter waves to increasing the water levels and hence erosion became excessive.

TABLE 2

Sea level characteristics and tidel range at Alexandria, Rosetta and Burullus (in cm)

Stretch	HHWL	MHWL	MWL	MLWL	LLWL	Tidal range
Alexandria	51	22	13	4	−37	18
Rosetta	68	26	17	8	−28	18
Burullus	68	36	28	20	−35	16

Table 2 illustrates the characteristics of water level at Alexandria, Rosetta and Burullus. It is clear that the average tidal changes along the coast are small; the difference between MHWL and MLWL ranges from 16 cm to 18 cm. However, the monthly tidal range not exceeding 24 cm most of the time.

Water level characteristics were drawn in order to investigate the variations along the western coast of the Nile Delta *(Fig. 6)*. It is indicated that the water levels increase from Alexandria to Burullus. The mean water levels at Alexandria, Rosetta and Burullus were found to be 13 cm, 17 cm and 28 cm respectively. The difference in MWL from Alexandria to Rosetta was 4 cm and from Alexandria to Burullus it was 15 cm. Such eastward increase in the sea level coincides with the predominate direction of longshore current which feeding the coast from west to east.

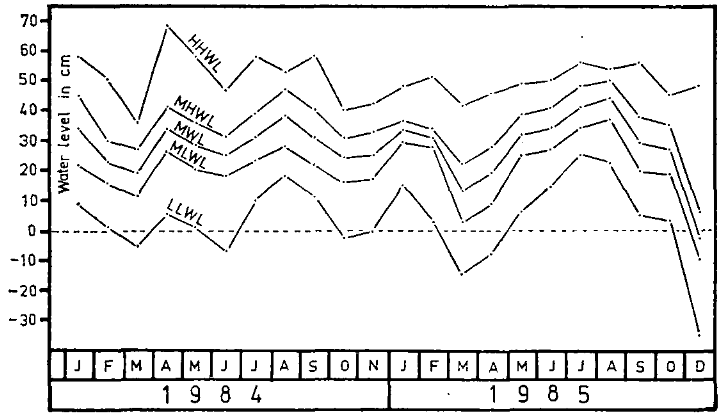

Fig. 5. Sea level changes at Burullus, 1984—1985

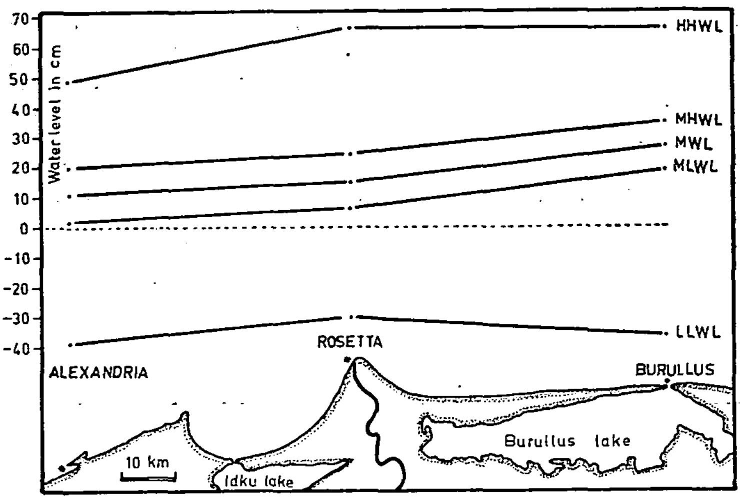

Fig. 6. Sea level variations between Alexandria and Burullus

Impacts of sea level rise in aquifers and estuaries

El-Fishawi and Fanos (1989) reported that the rise in sea level along the Nile Delta coast was estimated to be 10 cm for the period 1926—1973 with a rate of 2.2—2.9 mm/year. Hicks (1978) and Hicks *et al.* (1983) estimated an average rised of 2.6—3.7 mm/year along the Atlantic coast for the period 1921—1975. The predicter sea level rise in future will have an important impact on society. As ground water is removed and aquifer approaches equilibrium with current sea level, the salt front will move farther inland from the sea to recharge aquifers and hence increase the salinity. Hull and Titus (1986) estimated that a 73 cm rise in sea level would increase the maximum thirty-day chlorinity at Delaware River from 135 mg/l to 305 mg/l. High concentrations of sea salts at water intakes would create public health risks, increase the cost of water treatment and damage plumbing and machinery. High salinity could also upset the ecology of the estuary.

Recently, many wells were drilled along the northern coast of Egypt for land reclamation, irrigation and industrialization. Therefore, it is recommended to:

1. Control the ground water exploitation in the northern coast to reduce subsidence and salt water intrusion in fugure.
2. Use a mathematical model to study salinity changes in the estuaries and aquifers of the Nile Delta.

SUBSIDENCE OF COASTAL LANDS

Evidences for continued subsidence during the last 2000 years could be seen in Alexandria, Burullus lake, Manzale lake and Sinai. In the western part of the Nile Delta coast, Ptolemaic and Roman settlements are now found at depths between 5—8 m below sea level (Toussoun, 1934). Of course, the site of these settlements is deeper than can be accounted for by a sea level rise of 1.5 cm/100 years. The ancient monuments between Alexandria and Abu Quir, originally were built on land, had been submerged by the sea water. The coastal lakes could owe its existence to subsidence caused by earthquakes (COASTAL PROTECTION STUDIES, 1978). The structure in a sheltered embayment and such soil layers could be susceptible to subsidence of 1—2 m or more due to collapse of the loose soil structure under vibration. Also ruins of ancient villages on numerous islets in the coastal lakes show clearly the invation the sea to the agricultural land that had been utilised by the ancient inhabitants of these villages. The base of the ruins of Tennis were said to be below the level of Manzala lake. Furthermore, the remnants of two forts near Burullus outlet were visible below the sea in 1930, but they have now disappeared. The old site of Burg El-Burullus village is now about 2 km in the sea.

Published informations on the subsidence rate along the Nile Delta coast are few and show wide variation. In the Suez Canal stretch, a steady sinking of 1.2 mm/year since 1860 has been documented by GOBY (1952). Archeologists have calculated a definite rise of sea level relative to the land of 2.6 m in the last 18 centuries, corresponding ot an average of 1.4 mm/year (IBRAHIM, 1963). The eastern part of the Nile Delta indicated subsidence of some 10 m over at least 20,000 years (0.5 mm/year) and subsidences of few centimeters only during the last 2,000 years (COASTAL PROTECTION STUDIES, 1978). Considerable subsidence of the coastal zone is indicated by the 10—50 m thick layer of post 8,000 BP nearshore marine, lagoonal and deltaic sediments in the NE part of the Nile Delta (CONTEULLIER and STANLEY, 1987). At Port Said, an independent record of neotectonic motion for the period 1922—1950 indicated a subsidence of 4.8 mm/year (EMERY *et al.*, 1987). The Holocene thickness map points to the considerable subsidence in the coastal lower delta plain in the last 6,000 years (SESTINI, 1988), dated sequences suggest rate of subsidence of 1.5 mm/year. Higher subsidence rates ranging from about 4.5 mm/year to 5.0 mm/year for at least 7,500 years are calculated by STANLEY (1988). In fact, long-term subsidence rates of 5 mm/year are higher compared to rates at other much larger and thicker delta deposits, i.e. the rate of subsidence of the lower part of the Mississippi River Delta is found to be less than 2 mm/year as mentioned by STANLEY (1988).

To sum up, evidences indicate that erosion may be partly related to subsidence. However, more detailed work could answer the question of whether-eroded areas along the coast have subsided or the sea level has steadily increased.

CHANGE IN THE RIVER NILE LOAD

The relationship between the recent coastal erosion and the changes in the River Nile load can be traced if one of the important questions that the scientists try to answer: how much discharge and sediment were brought down by the Nile to Egypt from its upper reaches. Therefore, an attempt was made to show if noticeable change has occurred in the Nile levels, discharge and load during the recording period, then their repercussions must be related to the climatic change over the Nile basin.

It has been stated that the Nile flood levels *(Fig. 7)* were particularly high in the period 1840—1900 and that they have been significantly lower in the period 1900—1944 (QUELENNEC and KRUK, 1976). These features will be considered with the variations of the annual discharge and sediment load brought down the delta by the Nile.

Time series of total annual discharge of the Nile at Aswan (Fig. 8) was discussed by the COASTAL PROTECTION STUDIES (1978). The variation in the natural river flow

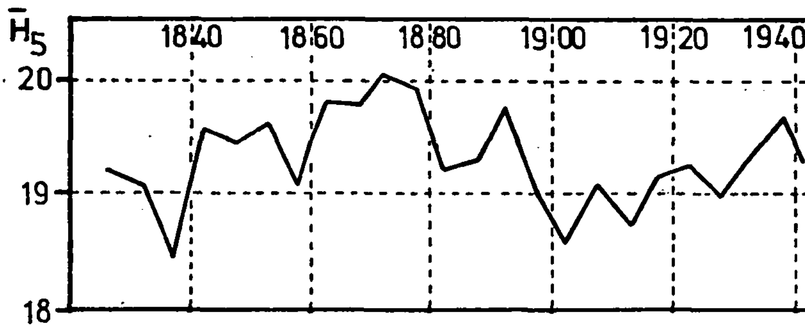

Fig. 7. Five years averages of the Nile maximum levels at Rodah (Cairo), 1825—1944 (after QUELENNEC and KRUK, 1976)

at Aswan indicated a difference of 27% between two sub-series during 1870—1971. The average annual discharge was estimated to be 107×10^9 m^3/yr during the period 1870—1902 and 84.4×10^9 m^3/yr during the period 1903—1971. Someone may relate this difference to the effect of the Low Aswan Dam constructed in 1902. In fact, a comparison between the annual Nile discharge recorded at Wadi Halfa (upstream) and Aswan (downstream) indicates an overestimation at Wadi Halfa to be of an order of magnitude of about 10%. But this overestimation of 10% can not explain the 27% difference in the two published sub-series during 1870—1902 and 1903—1971.

The averages of the yearly Nile sediment load at Gaafra *(Fig. 9)* have been estimated (COASTAL PROTECTION STUDIES, 1978) to be 200 million tons/yr for the period 1825—1902 and 160 million tons/yr for the period 1903—1963 (25% decrease). It is quite clear that the Nile suspended sediment load was heavier in the 19th Century during the periods 1860—1883 and 1890—1898 than it has been since 1900. In addition, the quantities of silt deposited in the Egyptian irrigated areas in 1886 was estimated to be 37 million tons; it decreased to be 22 million tons in 1959. Moreover, the amount of the sediments brought to the Mediterranean through the Rosetta and Damietta branches decreased with an average of 25%. During the period 1825—1902, an average of 162—175 million tons of sediments would annually reach the Mediterranean and then decreased to be 130—140 million tons during 1903—1963.

To sum up, a significant difference occurred in the Nile load prior and after 1900. The Nile flood levels became lower and the annual discharge and sediment load

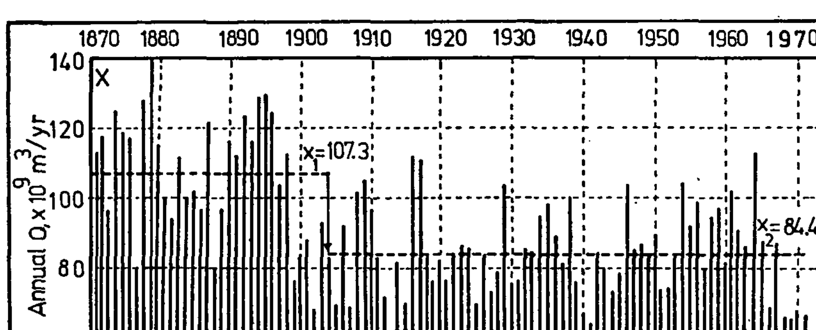

Fig. 8. Natural annual discharge of the Nile at Aswan, 1871—1971 (after COASTAL PROTECTION STUDIES, 1978)

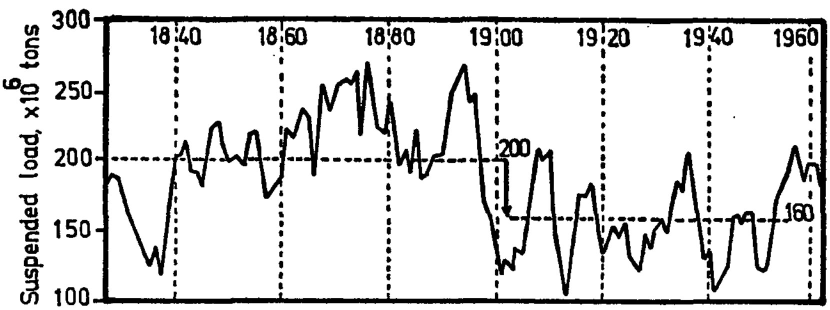

Fig. 9. Estimated suspended sediment load at Gaafra (Nile), 1825—1963 (after COASTAL PROTECTION STUDIES, 1978)

particularly decreased. The decrease of the Nile discharge and load due to reduced monsoonal rainfall over eastern Africa (ROSSIGNOL—STRICK, 1983) initiated a period of coastal instability and of headland recession. The cyclic variability of the Nile floods (HASSAN, 1981; HAMID, 1984) related to climate and precipitation change in east Africa had resulted during Dynastic times (3050—330 BC) in periods of economic stagnation. It is most likely that the changes occurred in the River Nile at Aswan since the beginning of the 20th century is the consequence of a slow climatic oscillation of more than 100 years period. On the other hand, HARRIS (1979) mentioned that the annual mean discharge decreased from 43.5 km^3/yr to 4.4 km^3/yr and the suspended load decreased from 60 million tons/yr to 5 million tons/yr after the construction of the Aswan High Dam in 1964. Therefore, the High Dam may play a minor part in the changing coast because the coastal erosion has been observed long before its construction.

CONCLUSIONS

1. Recent coastal erosion of the Nile Delta has been observed since 1909. The loss of coastal lands for the period 1909—1988 at Rosetta, Burullus and Damietta was about 14.7, 0.44 and 21.0 million square meters respectively. The fastest rate of shoreline receding was found at Rosetta (58 m/yr) if it is compared to 41 m/yr for Damietta and 3.8 m/yr for Burullus.

2. Sea level change is essential in the problem of coastal erosion. The average tidal changes along the Nile Delta coast are small and range between 16 and 88 cm and not exceeding 24 cm for the monthly readings.

3. Summer seasons at Burullus have higher sea levels than those in winter ones. The summer swells may increase the sea level causing erosion of the beach and coastal dunes near Burullus. In contrast, sea levels of Rosetta become higher in winter than those in summer. Severe coastal erosion at Rosetta headland therefore may be related to the effect of the winter waves to increasing the sea level.

4. The sea level increases from Alexandria to Rosetta and up to Burullus; the mean sea level for each area is 13, 17 and 28 cm respectively. Such eastward increase in the sea level coincides with the predominant direction of longshore current which feeding the coast from west to east.

5. Evidence for continued subsidence could be seen in many areas along the coast. The subsidence rate on published studies ranges between 0.5 and 5.0 mm/yr and will increase the predicted sea level rise.

6. A significant difference occurred in the Nile load piror and post 1900. The Nile flood levels became lower and the annual discharge and sediment load particularly decreased. Such phenomena may explain the cause of erosion on the Nile Delta coast since 1900. On the other hand, the construction of the Aswan High Dam in 1964 has reduced the Nile discharge and sediment load to insignificant quantities and hence causing accelerated erosion.

7. Causes of recent erosion along the Nile Delta coast may be related to the action of the following factors together: (a) Decrease of Nile discharge and sediment load since 1900. (b) The part played by the Aswan High Dam. (c) Continued subsidence of the coastal areas. (d) Sea level rise.

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